A method for detecting the presence of radar signal
emitters, an Electronic Support Measures unit and a system
for determining the position and identity of said emitters.

Field of the invention

5   Radar ESM systems are used to detect and identify radars
present in an area, by determining the direction of
arrival, and emitter characterization of radar pulses.

Technical Background

Such systems include a receiver covering the pertinent
10   radar frequencies. The receiver needs to cover a wide radar
frequency band (typical 2-18 GHz) with 360° of angular
coverage. At the same time, the system must perform
thorough analysis of each received pulse in order to
identify radar emitters. The system should be man-portable
15   in field, and should be able to operate with battery power.
Multiple systems should be able to find emitter position
(both bearing and range).

Three main solutions are known:

Wide bandwidth crystal receiver

20   A crystal receiver may be used to cover the entire
bandwidth. This receiver detects the signal envelope, and
coarse pulse parameters may be measured. At least four such
receivers are needed to achieve an angular coverage of
360°.

25   The wide bandwidth crystal receiver is capable to perform
coarse pulse analysis only. Important pulse parameters such
as carrier frequency and frequency or phase modulation are
lost. Thus emitter characterization is coarse at best. In a
scenario with multiple emitters, the use of two or more
30   ESM-receivers at different locations to position the target
emitter may fail since emitters received in one receiver

may be associated with a different emitter received in
other receivers.

Parallel receivers

Multiple receivers are used to cover the entire bandwidth.
With current technology, approximately 20 parallel
receivers may be used to divide the entire bandwidth into
sub-GHz channels, which in turn may be processed with
current digital processors. In order to cover 360°, at
least 4 such receiver packs with the antennas pointing in
different directions are needed to perform direction
finding.

The parallel receiver solution performs high quality pulse
measurement, and may therefore be used for emitter
characterization. Determining emitter position may be
performed when two or more receivers at different locations
are used, since each pulse and each emitter may be
identified. On the other hand, this solution requires
massive parallelism in both radio hardware and processing
hardware. The result is high weight and very high power
consumption rendering this concept useless for man-portable
operation.

Scanning receivers

In order to perform detailed pulse analysis, a single
narrowband receiver may be used for each antenna direction.
The receiver is used to scan the entire frequency bandwidth
sequentially. Detailed pulse analysis may be performed
within the narrow instantaneous bandwidth.

The scanning receiver may be built as a compact unit with
low power consumption, and may also provide detailed pulse
measurement. The problem with this receiver configuration
is the low probability of intercept due to low
instantaneous bandwidth. Radars operating with single scan
policy will most probably not be detected.

Brief summary of the Invention

It is an object of the present invention to provide an ESM system for detecting the presence of radars in an area that covers an adequate instantaneous bandwidth and is able to

5   perform a detailed pulse analysis in order to identify the emitter source.

Another object is to provide a system with the above features while being light in weight and power efficient.

These objects are met by a method, an Electronic Support
10   Measures unit and a system according to the present invention as covered by the appended patent claims.

Brief description of the drawings

The invention will now be described in detail in reference to the appended drawings, in which:

15   Fig. 1 shows a number of ESM-units according to the present invention in use; multiple ESM-sensors are networked for determining the posistion of a radar emitter, using a common emitter database for recognition,

Fig. 2 shows the physical design of a prototype receiver,

20   Fig. 3 is an overview of a system according to the present invention,

Fig. 4 shows the frequency band splitting and down conversion scheme used in the inventive system,

Fig. 5 is a block diagram of the receiver front end,

25   Fig. 6 is a block diagram of the receiver's second stage,

Fig. 7 is a diagram showing the Fourier transform of a received pulse; used for calculating the carrier frequency of a radar emitter,

Fig. 8 is a diagram showing a pulse from a radar emitter; used for calculating the pulse width,

Fig. 9 is a diagram showing the gain of three different antennas; used for calculating Direction of Arrival based
5 on pre-calculated antenna lobe calibration function,

Fig. 10 shows received pulses plotted in a DOA/frequency-diagram,

Fig. 11 shows the pulses received from a radar emitter; used for measuring emitter antenna beam-width and rotation
10 time.

Detailed description of the invention

Fig. 1 shows a typical setup for an ESM receiver system. A number of ESM-units 1 - 4 are placed in the terrain along a coastline. Each ESM-unit is adapted to receive and analyse
15 signals emitted by radars present in the surrounding area. In this case a tanker 5 is sailing along the coast, while its radar is constantly scanning the horizon. Each ESM-unit 1 - 4 receives the radar signals, resolves the direction of arrival and identifies the signature. The ESM-units are
20 connected in a network. Said network includes a control center 6. In the control center, the data received from the ESM-units 1 - 4 are compared and analysed in order to find the position of the radar source (tanker 5) and its identity (based on the signature of the radar pulses and a
25 database of known signatures).

Each ESM-unit 1 - 4 includes a number of antennas pointing in different directions, receivers and signal processing circuitry. Each antenna is covering a sector of the surrounding area, and the total assembly is covering the
30 whole horizon.

The Receiver Unit
The physical design of a prototype ESM-unit according to the present invention is shown in Figure 2. 12 antenna

elements are used to cover 2 to 18 GHz in 6 directions. In
each direction two antennas are used; the lower large
antenna covering the frequency band of 2 – 6 GHz, while the
small upper antenna covers 6 – 18 GHz.

5   The ESM-unit or receiver system consists of two units,
namely: The Receiver unit 7 (Antenna, Receiver and
Navigation sub-unit) and the Processing Unit 8 as shown in
figure 3.

10   The antennas 10a, b – 16a, b are delivering their signals
to the receiver unit 7. In the receiver unit 7 the signals
from each of the upper antennas 10a – 16a are split into
three 4 GHz wide sub-bands, i.e. a 6 – 10 GHz sub-band, a
10 – 14 GHz sub-band, and a 14 – 18 GHz sub-band. The three
15   sub-bands together with the 2 – 6 GHz sub-band from the
lower antenna are converted into a single intermediate
frequency (IF). There is one IF channel for each antenna
set, i.e. a total of six IF channels. IF channels of
opposing antennas are combined into one channel (not shown
20   in the figures); thus providing a total of three IF
channels.

In the receiver's second stage, Figure 6, the 4 GHz IF is
again split into four 1 GHz wide sub-bands, which are
25   further down-converted and combined into baseband channels
of 1 GHz bandwidth. Thereafter the signals are sent to the
processing unit 8 for digitalization and processing. The
conversion scheme is detailed in Fig. 4.

In addition to the antenna/receiver chain, this unit
30   contain an attitude determination unit (compass) 18 and a
GPS antenna 17. All is contained within a single unit that
may be mounted either on a tripod or fixed on an antenna
mast.

6

Radio design

The receiver front-end is shown in Figure 5. The Ant Lo
input receives the signal from one of the lower antennas
10b – 16b, while Ant Hi in receives the signal from the
5   upper antenna 10a – 16a. The signals are filtered in band-
pass filters 20a – 20d, whereupon the signal from the upper
antenna is split into three sub-bands. The signals from the
band-pass filters are amplified in low-noise preamplifiers
21a – 21d and fed to mixers 22a – 22d. In the mixers 22a –
10   22d, the signals are downconverted to IF channels of
identical frequency range and filtered in another set of
band-pass filters 23a – 23d. The outputs from the IF-
filters 23a – 23d are combined in an adder 25.

Signal from each sub-band are thus overlaid each other.
15   Since the signals are pulsed, the probability of
simultaneous signal from different channels is quite low.

In order to determine direction and frequency of incoming
pulses, broadband pulse detection is performed in each of
the original channels before combining. For this end, four
20   detectors 24a – 24d are included, one in each IF channel.
The outputs from the detectors are fed to a comparator 26,
for identifying which channel a given signal occurs in.

The second stage of the receiver is shown in Figure 6.
Again, the first IF signal received from the front- end in
25   Figure 5 is split into four sub-bands in band-pass filters
27a – 27d, amplified in amplifiers 28a – 28d, down-
converted in mixers 29a – 29d, filtered in band-pass
filters 30a – 30d and combined in adder 32. The resulting
baseband channel in the range 0 – 1 GHz has a bandwidth
30   matched to the A/D converters in the subsequent processing
system (typical 1GHz with 2.5 GS/s A/D converters).

In addition a oscillator and control block (not shown) is
needed to generate all oscillator frequencies, control

signals to the amplifiers and handle trigger signals from
each of the channels.

The resulting channels are narrow enough for A/D
conversion, and the pulses may be processed with one single
processor. The necessary number of parallel A/D converters
is equal to half the number of antenna directions (typical
three with six antenna directions).

The Processing Unit

A four-channel 1GS/s A/D converter is used for
digitalisation of the receiver channels. A GPS receiver is
used for position determination, and the compass in the
Antenna unit is read for antenna attitude determination.
The processing unit digitises pulses received, performs
pulse-processing, de-interleaving and multi-path analysis
before emitter processing is performed. The following
process is performed on the detected pulses:

For each pulse:
 o Convert pulse series to complex form
 o Measure Pulse peak amplitude and average amplitude
 o Measure Direction of Arrival (DOA) based on
  amplitude difference and phase difference in the
  three channels
 o Measure Pulse Width (the duration of the pulse)
 o Measure Carrier frequency (corrected according to
  sub-band detectors)
 o Measure Time of Arrival (TOA)
 o Insert pulses into frequency / DOA histogram

After detection of a predetermined number of pulses or upon
reaching a predetermined time limit perform:
  o De-interleaving (identifying which pulses come
   from the same emitter):
    • Based on frequency/ DOA histogram
  o Perform emitter analysis:
    • Improve DOA measurement by averaging

- Perform echo-recognition by identifying
  "same" emitter in different directions
- Perform emitter antenna analysis
  (rotation speed and beam width) based
  on pulse amplitudes
  o Perform emitter classification based on all
    emitter parameters (excluding DOA)
  o Perform emitter recognition based on all emitter
    parameters (excluding DOA) and sampled pulse
    waveform compared to emitter library.

If multiple ESM-sensors observes the same area, DOA
information from neighbouring ESM-sensors to triangulate in
order to find emitter position

At this stage, data may be displayed locally or set to the
network for sensor fusion with other sensors. If multiple
ESM sensors are connected in a network, local sensor fusion
may be performed to provide target positioning. In addition
emitter recognition analysis is performed using either a
local or network based emitter database. Figure 4 shows the
use of multiple ESM-receivers for emitter position
determination. A common emitter database (shown as a green
oval on shore) is used to convey emitter information from
one ESM-receiver to another.

Emitter database maintenance is envisioned integrated with
the ESM system. Whenever a new emitter is encountered, the
emitter must be identified by other means, but the data is
stored for recognition purposes.

The Processing Unit controls the Antenna, Receiver and
Navigation unit with respect to frequency coverage. During
battery operation, a several non-continuous operation modes
may be specified in order to expand battery life.

The processing unit is contained in a single unit with integrated batteries in man-portable mode or rack mounted in platform installation.

Pulse processing algorithm

5   The processing system receives pulse signal from the radio
     head. The pulses are digitized in the sampler system such
     that each pulse is stored as 3 series of samples for each
     pulse, one series for each channel. In order to determine
     the pulse parameters, each pulse data series is analyzed
10   with the following algorithm:

   o Perform real to complex FFT (Fast Fourier Transform)
     for all 3 series
   o Determine carrier frequency:
15   • Locate peak power in the series (n_{max}), see Figure
          7.
        • Calculate carrier frequency: $f_c \approx \dfrac{n_{max}}{N} f_s + f_{chan}$ where N is
          number of samples in series f_s is sampling
          frequency and f_{chan} is the frequency offset of the
20   radio channel (received from the radio head)

   o Perform complex inverse FFT (The samples are now
     complex, and the series length is halved)
   o Scan series and determine peak power (P_{max}) for each
25   channel and compute −3dB level: $P_{3dB} = P_{max}/2$
   o Scan series and locate −3dB crossings, calculate 3dB
     pulse width (see Figure 8)
   o Calculate time of arrival as data series start time +
     offset to first 3dB crossing
30 o Estimate direction of arrival from pulse series from
     peak amplitudes:
   o Center channel (Ch$_0$) has maximum power (from radio
     head)
   o Calculate DOA from predetermined antenna lobe
35   calibration function: $DOA = g(P_{-1}, P_0, P_1)$ see Figure 9.

o Insert pulse with parameters into 2-dimensional
histogram, indexed by carrier frequency and direction
of arrival.

In summary, the process of finding the direction to a radar
emitter includes three steps:

1. The detectors in the IF channels are used to decide if a
given signal is received by a front or rear antenna.

2. A comparison between the signal amplitudes in the IF
cahnnels, together with the antenna characteristics (Fig.
9) is used to get a coarse estimate of the direction to the
emitter.

3. A phase-comparison between the channels is used to get
the direction with full accuracy. Step 2 above is needed as
a preparatory step, as the phase-comparison is ambigous.

Emitter processing algorithm

After detection and processing of a predetermined number of
pulses (or upon reaching a predetermined time limit), a
number of pulses from the observed emitters have been
analysed and entered into the histogram. An example with
two emitters i shown in Figure 10.

In order to de-interleave pulses (sort pulses by emitter),
pulses are extracted from the DOA/frequency histogram,
starting with the histogram cell with largest pulse count.
In the above axample, 3 "emitters" would be extracted,
namely pulses from emitter #1, pulses from emitter #3 and
fimally pulses from emitter #1 reflected off a reflector
(hillside, building etc). Each "emitter" is analyzed
according to:

o Calculate average and standard deviation of all pulse
parameters except pulse amplitude

o Perform Emitter antenna analysis (see Figure 11):

- Measure time between antenna main lobe passings (time from local maximum to local maximum)

- Measure antenna beam width (same principle as measuring pulse width)

5 o Perform emitter PRI analysis

- Measure time from pulse to pulse and calculate average

- Optionally: perform analysis of PRI variation (pattern recognition)

10 After emitter parameter estimation, the directions to and other parameters to all emitters are known. The list also includes "emitters" that are actually copies of other emitters due to reflections off diferent surfaces. These artifacts have the same parameters as the originating
15 emitter except Direction of arrival. In order to determine which emitter is the original the following analysis is performed:

o Compare peak amplitude. The artifact will most often have lower amplitude than the correct emitter

20 o Compare standard deviations of pulse parameters. The artifact will have larger standard deviations

The emitters are now analyzed and the direction of arrival, pulse parameters and emitter characteristics have been determined.

25 **Emitter position determination using multiple POS sensors**

Each sensor analyze pulses from the observed emitters. When emitter analysis is complete, the emitter parameters are sent to any neighbouring POS sensors by data-network.

Upon reception of emitter parameters from a neighbouring
30 POS sensor, this emitter is compared to all of the locally

detected emitters (using all parameters except DOA). When a
match is found, the position is determined by triangulation
(position of each POS sensor is known, DOA to the emitter
from each POS sensor has been determined, thus the emitter
5   position may be determined by simple geometry)

Emitter recognition / Emitter database

In order to recognize emitters from previous observations,
the emitter parameters are stored in a emitter database.
Upon reception of a new emitter, the emitter parameters are
10   compared with the parameters stored in the database. If a
match is found, the emitter is assumed to be the same as
the one found in the database. If not, the new emitter is
stored in the database.

The database may either be stored locally or accessed by
15   data network. Using a networked database provides the
ability to share information about new emitters between
multiple POS sensor as soon as the new emitter is detected.

Direct conversion embodiment

While the inventive receiver has been described employing a
20   two-stage conversion scheme with an intermediate frequency,
and which is the preferred embodiment of the invention at
the present state of the art, the concept of the invention
has a wider application.

Under certain circumstances, a direct conversion receiver
25   can be preferred. In this version (not shown), the signals
from the antenna(s) are split into a number of sub-bands
and mixed directly down to baseband, before they are
combined in an adder unit. The output from the adder is
digitized and processed as in the example described
30   earlier.

Technical Abbreviations

A/D - Analog/Digital

DOA - Direction of Arrival

5   ESM - Electronic Support Measures

GPS - Global Positioning System

GS/s - GigaSamples per second

IF - Intermediate Frequency

PRI - Pulse Repetition Interval

10   TOA - Time of Arrival